Design of a Multi-Level Intake for Temperature Control featuring a Lake Tap at Cougar Dam, Vida, Oregon

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Abstract: The intake structure at Cougar Dam, Oregon is being modified to provide temperature control of project outflows. The system will utilize a multilevel intake structure to modify the outflow water temperatures to more closely match the natural cycle of water temperatures in the river. The change from the natural cycle was altered when Cougar Dam began operation in 1964, disturbing the life cycles of the local fish species and reducing fish productivity in this system.

A new 235-foot-tall, rectangular concrete wet well is being attached to the upstream side of the existing intake structure. Six R.O. and three penstock weir gates will be installed to selectively withdraw water from different temperature strata in the reservoir into the wet well. The existing regulating outlet and penstock intakes will draw from within the new wet well. The system will provide water temperature control for 95% of all average annual project outflows and flows up to 2,000 cfs.

The reopening of the original concrete-plugged diversion tunnel was required to drawdown the reservoir for construction of the new tower. A new flow control gate chamber and concrete lined channel were added to the tunnel section below the plug. The tunnel tap caused an uncontrolled release from the reservoir under 270' of head with transient pressures up to 800 feet head. The tap procedure was selected through computational and a physical model studies. The tunnel tap was successfully conducted on 2/23 2003, and transient timing and flows were near the predicted quantities.

Introduction

As a component of the Willamette River Temperature Control McKenzie Subbasin study, Portland District was authorized to construct Cougar temperature control structure in 1998. A study completed in 1995 indicated that Cougar would be the first project modified in a staged construction project to include Blue River dam. Construction of a multilevel intake was determined to be the most efficient system for providing much greater control of water temperatures downstream of the project. The details of this project are discussed herein.

Figure 1 Aerial Photo of Cougar Dam, Powerhouse, and Reservoir Outlet Exit.

Background

Cougar dam is located on the South Fork of the McKenzie River approximately 4.5 miles upstream of the confluence with the mainstem McKenzie. The dam impounds Cougar Lake, with a capacity of approximately 219,300 acre-feet. The project consists of a rock-fill embankment about 1,500 feet long and 452 feet high, an emergency gated spillway with a design capacity of 76,140 cfs, a penstock to power two small Kaplan turbines, a regulating outlet and what was a decommissioned diversion tunnel. The original project was completed in 1963. Project outflows are typically on the order of 400 to 1,200 cfs range.

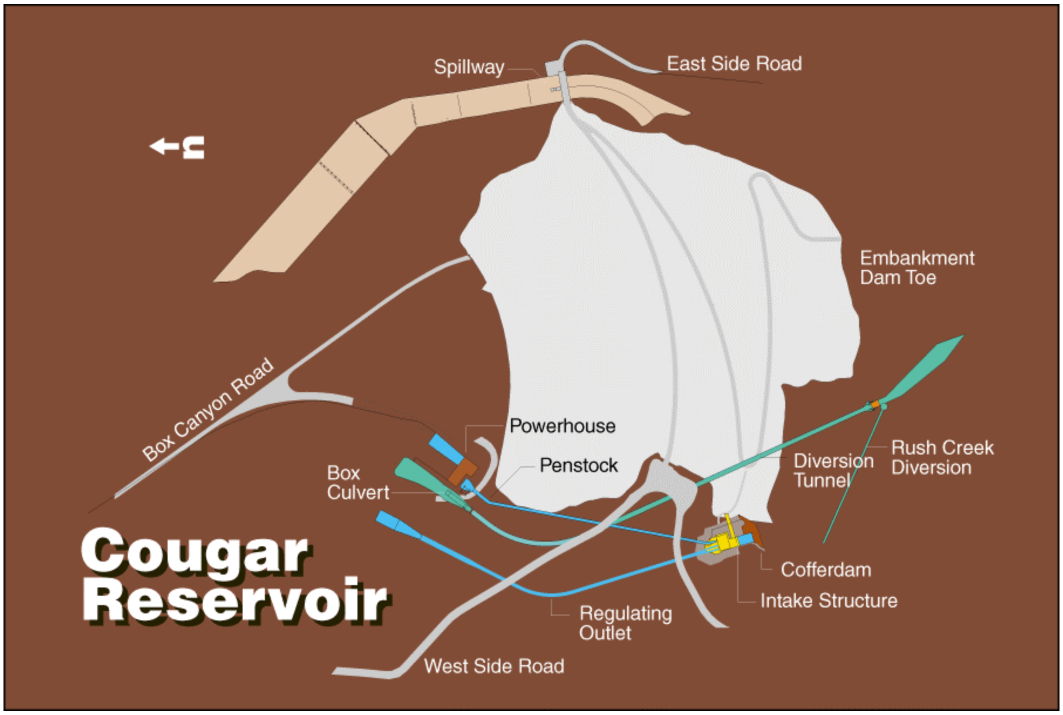

Figure 2 Plan View of Cougar Project

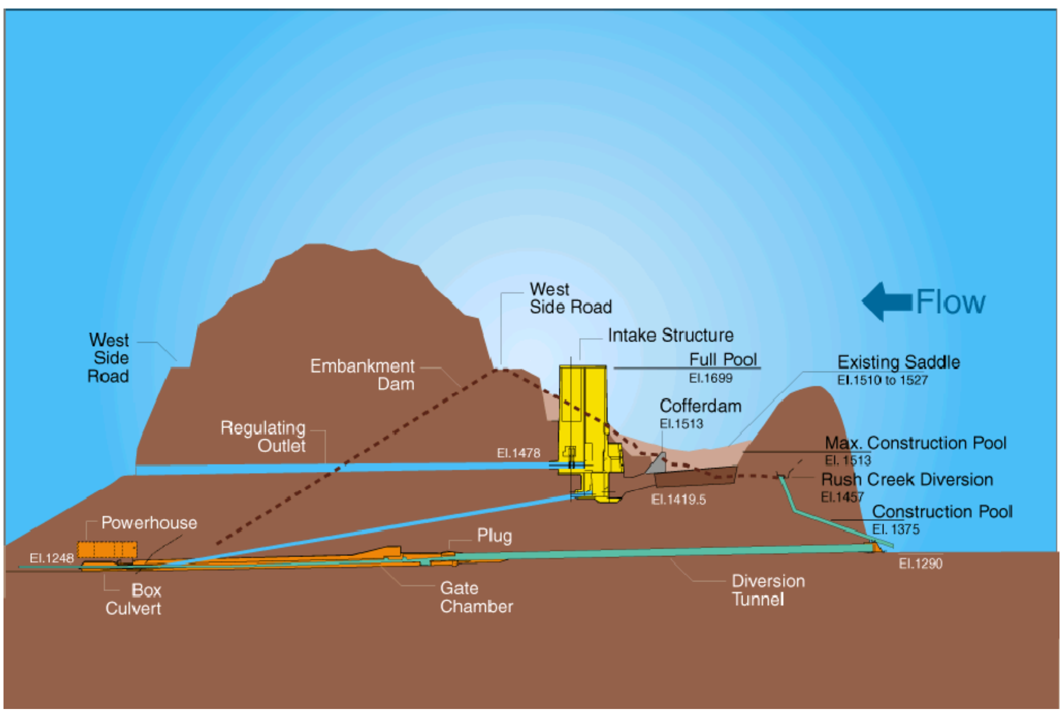

Figure 3 Elevation View of Cougar Project

Objective

The objective of the project is to restore the seasonally varying temperature conditions as close as possible to target temperatures established by consultation with fishery resource agencies. Currently the project is releasing water that is colder than flow under pre-project conditions in the spring/summer and this delays upstream migration of spring Chinook salmon. In the fall/winter, the project is releasing water that is warmer than pre-project negatively affecting prespawning mortality and resulting in premature fry emergence.

Design

The original design of the selective withdrawal structure utilized eight temperature control ports. After extensive analysis it was determined that withdrawal over these discrete intervals did not allow the flexibility necessary to adjust temperatures as needed for biological reasons. Therefore, a new design was selected utilizing submerged adjustable weirs.

Details

To allow for proper operation of the submerged weir system, a new 235-foot tall, rectangular concrete wet well will be attached to the upstream face of the existing intake structure. Sliding weir gates will be operated as submerged weirs to allow withdrawal of water from different temperature strata, typically the warm upper surface layer, in the reservoir into the wet well to meet target outflow temperatures. The existing regulating and penstock intakes will draw water from the new wet well. The system will provide water temperature control for 95% of all average annual daily project outflows, which correspond to flows up to 2,000 cfs.

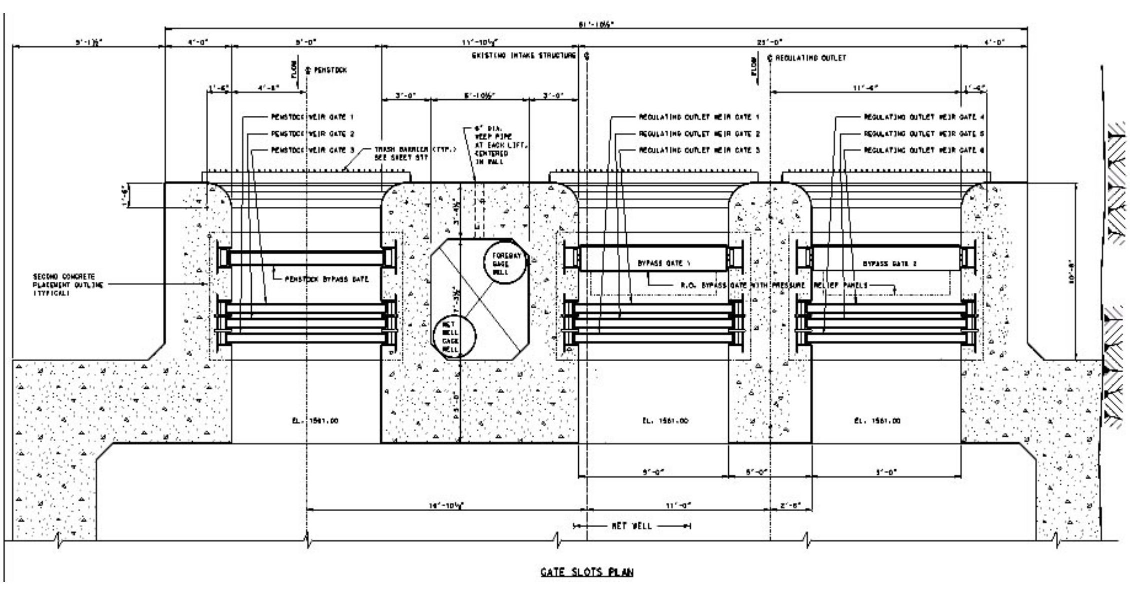

Figure 4   Plan View of Cougar Dam Water Temperature Tower Weirs

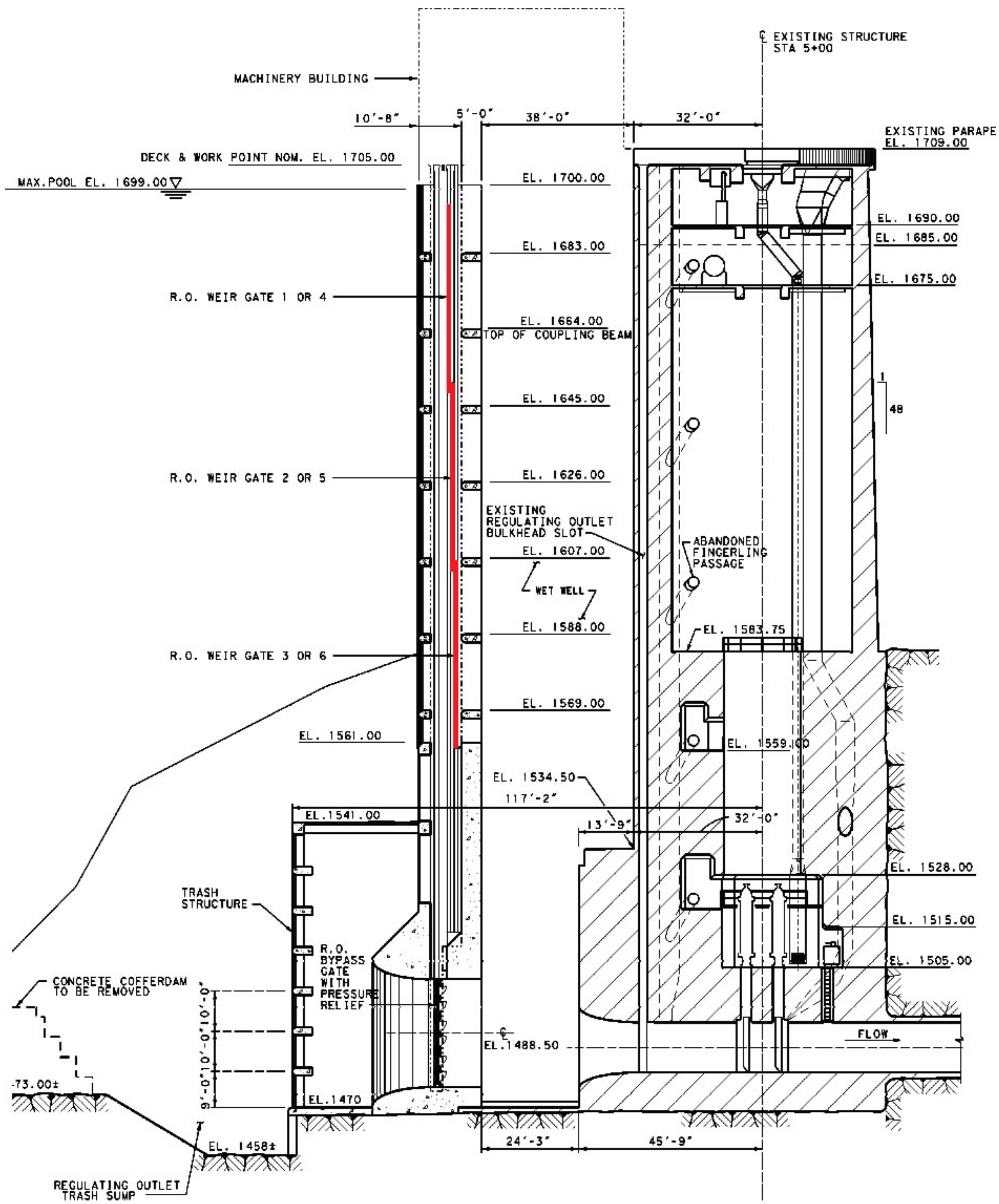

Figure 5 Elevation View of Cougar Dam Water Temperature Tower

Construction

Construction will occur over 4 years. The first year entailed reconstructing the diversion tunnel for reopening and operation. The diversion tunnel had a concrete plug in place since the original construction. To bring it back online, regulating facilities were built immediately downstream of the plug. Then the plug was mined out and tapped to reopen the diversion tunnel to the lake. The pool was drawn down over 7 months (April – October) to divert flows away from the main tower and wet well construction. This will be done for three consecutive years. The project is required to maintain its flood control mission throughout construction and therefore the pool will go up beyond the construction protective cofferdam each year. The reservoir is being held at a target elevation of 1,375 feet during construction to minimize sediment transfer during construction. The powerhouse cannot be operated during construction, so the Project has taken advantage of the outage to do some needed powerhouse rehabilitation.

Hydraulic Design

The weirs are arranged in leafs with a height of 35 feet. Each leaf can be operated independently. This allows the system to pass flows underneath any of the weir leafs for mixing from different elevations. Three submerged weirs structures will be used to control the water temperature entering the wet well. The weirs can be operated from the maximum pool elevation of 1,699 feet to the lowest invert elevation of 1,561 feet. The weir lengths are 9 feet and are centered over the regulating outlet works and the penstock. The RO bypass bulkheads can also be raised as necessary to provide temperature control opening at the lowest possible point in the water column.

The operation of the submerged weirs will allow for skimming the uppermost portions of the water column for temperature control. The submergence will be adjusted based on discharge and temperature distribution in the reservoir. Any of the leaves can be lowered or raised to provide an opening at a deeper point in the reservoir. The depth of the opening will depend on the position of the weir leaves. The opening can be regulated to almost any size to provide colder water for mixing.

Two 9-foot wide by 27-foot tall openings and accompanying R.O. bypass bulkheads replace the two 11-foot by 20-foot intakes present in the Willamette Temperature Control Feature Design Memorandum (FDM). The openings are centered on the regulating outlet entrances. The regulating outlet bypass bulkheads will be raised to pass project discharges that exceed the capacity of the wet well. During operation of the temperature control device, pressure relief hatches mounted in the bulkhead will allow the wet well to self-stabilize in the event of a mis-operation or debris load that threatens the integrity of the structure. These hatches are designed to release at a head differential of 7 feet and are spring-loaded, automatically resetting once head differential is gone or reversed.

Trash Facilities

The intake trash struts will be nearly identical in spacing to the existing trash struts. A separate trash rack will be installed guarding the penstock intake. The cross-sectional area of the trashrack has been maximized because the interior trash rack will be inaccessible to mechanical cleaning. Cleaning will be performed by reverse flow through the area isolated by the penstock trash racks. Opening the penstock bypass gate and switching the project discharge from the penstock to the regulating outlets will reverse the flow through the trash rack. This will flush trash from the trash rack and through the regulating outlets.

Operation

At a discharge of 2,000 cfs and submergence of 15 feet the submerged weirs will normally operate at a differential of 1.5 feet. Weir position will be determined by temperature output required of the project. A combination of submergence, differential head and deep openings can be manipulated to meet temperature criteria. At any discharge warmer water can be reached utilizing a smaller submergence, which will result in a higher differential head. Likewise, cooler water can be reached utilizing a deeper submergence resulting in a smaller differential head.

During flood control events the weirs may be completely removed from the flow path by either being dropped below the lowest invert or raised up above the water and into the intake tower building.

Diversion tunnel

The Cougar diversion tunnel is mostly a rock-lined tunnel that was used for care and diversion during original dam construction. The tunnel was modified during 2001-2002 with the addition of a control gate chamber and high velocity conduit from the chamber to the exit to the river.

Tunnel History. The Cougar diversion tunnel was built to divert and bypass the South Fork McKenzie River during the original construction of Cougar Dam. The tunnel flow was not controlled. After the dam was built, the tunnel was closed with a concrete plug located near the middle of the conduit. In the 40 years since, the upstream half of the conduit lay deep underwater and the lower half was unsubmerged.

Purpose of reopening tunnel. The reservoir level had to be lowered for construction of the new water temperature control tower. The RO intake is too high to take the reservoir level down to the required construction level. The intake for the diversion tunnel is at elevation 1290 feet. The elevation of a reopened tunnel would provide sufficient reservoir drawdown for temperature tower construction.

Construction photo, McKenzie River flowing into diversion, intake tower in background, Cougar Dam.

RIVER CHANNEL AND LEFT BANK. Pictures taken progressively from Borrow Area to toe of Dam. Camera on East Side Road. Merritt-Chapman & Scott Corp., Cont. 59-270.

Figure 6 Construction Photo of Original Diversion Tunnel.

New Control Gate Chamber and Lined Channel. In reopening the diversion tunnel, provisions had to be made to control the reservoir discharge. A new gate chamber was installed downstream of the plug during the 2001-02 tunnel modifications. The chamber includes two 6 feet high by 2.25 feet wide sluice gates designed for high head discharge. The chamber is approximately 100-feet long and varies between 14 to 16-foot in diameter. The chamber includes rock traps to collect debris from the tunnel opening. Between the gates and the river exit, the remaining 800 feet of tunnel was lined with high velocity concrete. The exit velocities through the gates could reach as high as 200 ft/s. Thus the potential for cavitation through the gate openings and the downstream channel were a significant hydraulic design concern.

Tunnel Rating Curve. During the WTC FDM phase, a tunnel-rating curve was developed from a combination of physical modeling [3] and analytical methods. As the day of the tunnel tap neared during the EDC phase, the analytical methods were rechecked and refined. The result was increased flow rates in the rating curve by about 20%. After the tap, additional data was collected from the USGS stream gage. The following figure shows both rating curves with both gates fully open.

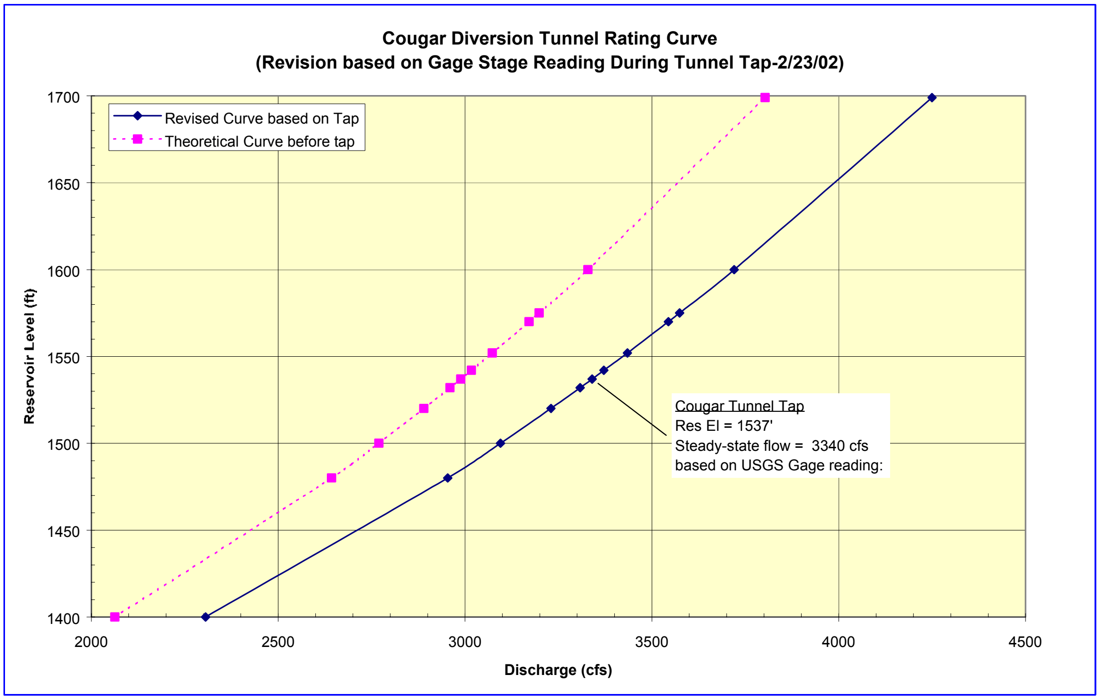

Figure 7 Cougar Diversion Tunnel Rating Curve, both gates fully open.

Tunnel Tap

The tunnel tap is the final and explosive opening of the tunnel plug to the reservoir. This is the defining climax of all the planning, engineering, construction, and escalating tension that built toward this moment. The success of the tap is revealed almost as suddenly as it occurs.

Tap opening procedure. The plug was alternately excavated through mechanical and explosive measures from the downstream end. The final stroke would be the tunnel tap blast, which opens the plug to the upstream conduit under residual reservoir head. As the construction crews whittled down the plug, the blasting contractor performed periodic trial runs to test the blasting procedure. The final blast was completed in precisely-timed increments over a total 0.4 seconds.

The gate chamber was dry and the gates were fully open during the tap. Cylindrical rock traps were excavated between the plug and gates to capture pieces of concrete plug that would be thrown or washed downstream during the blast opening.

Alternatives. The basic alternatives for the tunnel tap were the following procedures:

1. Wet tap—control gates closed and chamber filled with pressurized water.
2. Dry Tap—Gate chamber is dry during tap. There are several variations of this approach:
   a. Dry tap with multiple blasts—the multiple blasts would open plug in increments spanned over time to diffuse the effects of the transients

b. Dry tap with closed gates.
c. Dry tap with open gates.

After the WTC FDM phase, procedure 2-a (dry tap with delayed blasts) was the assumed approach. This method was developed in the ENSR lab [3] and showed the most promising means of limiting the transient heads. However after consulting with the blasting contractor during the EDC phase, it was determined the blasting caps were not reliable if exposed to flow for even a short time and the possibility of a partially opened conduit loomed. This meant other strategies of tap procedure had to be revisited.

The hydraulic Design section initially researched the question of 'wet' tap versus 'dry', and determined through research that the dry tap was safer because the more efficient transmission of the initial shock wave of the explosion through water would cause a much larger impact against the closed gates. This left two remaining dry tap procedures 2 b (closed gates) and 2 c (open gates) to assess.

Selected approach. The dry tap with open gates procedure (2 c) was selected. Preliminary analyses and anecdotal (unmeasured) results from the ENSR model indicated that the closed gate procedure might produce extremely high transient pressures. EC-HD developed a FORTRAN program to simulate transients from the tap. The results from the computer model confirmed that open gates procedure (2 c) was the safer approach, resulting in significantly lower transient heads.

Hydraulic Transient Analyses. Concerns for hydraulic transients from the tunnel tap were considered early on in the design process. As new information came available during the EDC phase, the EC-HD team had to modify the strategies and the means of evaluating these strategies.

*General Concerns***.** An upstream head of 270 feet was expected at the plug when the tap was to commence. The sudden opening of the plug under these conditions would lead to an initial acceleration of inflow into the chamber, which would at some later point drop off. It is the combination of the high flow magnitude and the severity of flow reduction, which can cause serious transient pressures.

Physical model. Previous work had been done in a 1:20 scale physical model at ENSR [3] lab to provide qualitative results during the design phase. (Because atmospheric conditions and viscosity do not scale with the Froude model, the data was qualitative rather than quantitative). The ENSR report recommended a 2-phase breaching process in which smaller opening would be first opened and 60 seconds would pass before the hole is enlarged to the final dimensions. However, this procedure was rejected during EDC.

Numerical model. The numerical model emerged out of need for more accurate and precise answers. EC-HD first performed a preliminary surge analysis for a 'dry' tap with the closed gates. A surge analysis procedure from Chaudry [1] provided an estimate of approximately 4000 feet of head increase in the chamber. This method could not be applied with an open gate setting.

The EC-HD team decided to more realistically simulate the transients using the method of characteristics and applying standard gas principals for the conditions inside the gate chamber. A FORTRAN program was developed to perform the simulation, using Wylie [5] and Tullis [6] as the chief reference sources. This model is documented in an EC-HD memorandum [3]. The estimate for maximum transient head for closed gate procedure was refined to about 1700 feet of head. The transient head for the open gate procedure was estimated to be about 800 feet.

Description of Transient Mechanism. When the plug is opened, the gate chamber rapidly fills with water (4 –10 seconds). The total area of the open gates is one-fourth the size of the plug opening, causing the water discharge to be more constricted at the gates. The maximum transient pressure then occurs when the bulk of the fluid discharge through the gates changes from air to water. The denser water does not pass as easily as the rapidly evacuating air. This leads to an abrupt drop in flow and pressure head increase, which both accompany a 'positive' pressure wave that travels back to the reservoir. The pressure wave is reflected back at the reservoir and after a few oscillations; the flow and head in the system will quickly steady out. The figure below displays the predicted results of the hydraulic conditions within the gate chamber during the tunnel tap with respect to time.

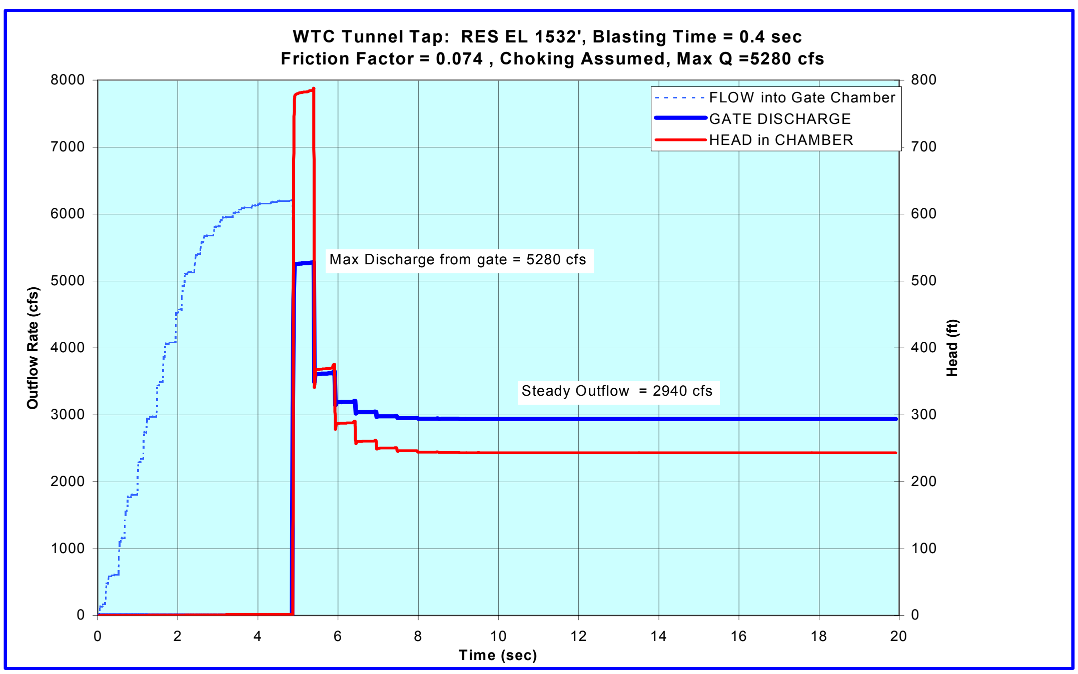

Figure 8. Transient Results for Cougar Diversion Tunnel Tap with Open Gates, Reservoir Elevation 1532 ft.

Reservoir Operation for Tap. Another tunnel tap concern was potentially high water levels downstream of the project in the wake of the tunnel tap. On one hand the high flows from the tap could overtop the banks; on the other hand, the tailrace needed to be kept high enough to prevent excessive erosion in the stilling basin. These conflicting issues were tackled by EC-HD analyses using HEC-RAS and the computed hydrograph of the tunnel tap (See Figure 8). A schedule of reservoir discharges preceding and following the tunnel tap were developed through coordination with NWD Reservoir Control Center (RCC) and Project Operations.

Day of Tunnel Tap. The construction section (CENWP-EC-CO) conducted a pre-meeting to coordinate assignments and safety. The project operators had adhered strictly to the RCC reservoir operations. The blasting contractor alerted the project team that the blasting charges were in place and the tunnel was evacuated. The tap was detonated in a sequence of incremental blasts that radiated from the middle of the plug. All the blasts were completed within 0.4 seconds.

Visual observations. The initial blast of air was seen at the tunnel exit (800 feet below the gates) in 5 seconds after the blast. The water started gushing out of the tunnel about 18 seconds after the blast. A large brown plume of silt accompanied the initial wave. Some large slabs of rock were forcibly relocated in the stilling basin. The discharge from the tunnel exit dropped significantly after another 10- 15 seconds. The level of the tailrace was raised about 3 feet and remained that way for another 30 minutes.

Available Data. The following data was collected during the tunnel tap:

- Videotape of the conduit exit with the sound recorded. This was used to determine the time it took for the air blast and water to reach the exit.
- Project operators logged the water levels in the project tailrace at about 5-minute intervals. After the tap, the water level rose 3 feet above pre-tap levels and hovered there for the next 30 minutes.
- Water levels were recorded at the USGS gage at frequent intervals. The predicted water level rise agreed favorably with the observed rise.

Pressure transducers were installed prior to the tap, but they failed or became plugged when the tap occurred and no useful data could be retrieved.

Evaluation of the Transient Prediction. The water level data at the downstream USGS gage gave rough confirmation of the timing and volume of flow associated with the predicted transient.
The time measured for the flow to reach the conduit exit was more useful. According to the program output, it would take 5 seconds before the main jet discharged from the chamber gates. With an initial outflow rate of about 5300 cfs, the velocity through the gates would be nearly 200 ft/s at the gates. Downstream, the velocity would be would decelerate rapidly due to the friction of the conduit, attenuation, and the effect of the tailwater in the lower half of the tunnel. A simple hydraulic profile, factoring in the tailrace level, produces a travel time of 12 seconds. This sums to a

total of 17 seconds after the blast compared to the 18 seconds recorded in the video. The best way to check the prediction would be an application of Computational Fluid Dynamics (i.e. Flow 3-D).

Conclusion

The successful lake tap has allowed construction to occur as scheduled. The project is in the third year of construction. The intake tower is proceeding as scheduled. Temperature control operation should begin in the winter of 2004/2005.

References

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